A Local Basal Area Adjustment for Crown Width Prediction

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ABSTRACT: *Nonlinear crown width regression equations were developed for 24 species common to the upper Lake States of Michigan, Minnesota, and Wisconsin. Of the species surveyed, 15 produced statistically significant ($P < 0.05$) local basal area effect coefficients showing a reduction in crown width with increasing stand density. No relation between shade tolerance and crown width was apparent, indicating the species-dependence of this parameter. Using adjusted R^2 as a guide, nonlinear crown width models adapted for local basal area ($NLCW_{adj}$) improved prediction for 20 of 24 species over a model lacking this component (NLCW). The ecological significance of the improvement shown for some species may be minor, but for others the difference was substantial (often 8%). North. J. Appl. For 18(1):22–28.*

Key Words: Nonllinear regression, crown width model, stand density, Lake States.

Accurate prediction of tree dimensions has become prominent as analysis techniques, models, and other statistical tools allow for the rapid evaluation of extensive volumes of data. Some parameters (e.g., diameter or age) are easy to measure with simple instruments and therefore have become cornerstones in forest inventories. However, research has shown that other variables not so easily collected are also good predictors of forest dynamics and can improve the reliability of tools like growth and yield models. One such parameter is crown size, which has received increasing attention as a means to estimate tree growth (e.g., Warrack 1959, Ottorini et al. 1996, Singer and Lorimer 1997). There are several approaches to calculating crown dimensions (for example, volume versus surface area versus vertical projection), but most entail the use of crown width. In addition to growth modeling, crown width has many other valuable applications. Aerial photograph interpretation has long depended on relationships between crown width and stem diameter for stand inventories (Gill et al. 2000), while others have used crown width to help estimate fine fuel loading (Meeuwig et al. 1979). Several measures of tree competition rely on crown width to adjust for tree-to-tree interactions (e.g., Krajicek et al. 1961, Bella 1971, Hatch et al. 1975). Some computer models also incorporate crown width to help define the structure of simulated canopies (e.g., Smith et al. 1992, Pacala et al. 1993).

Numerous crown width models have been developed, but perhaps the most common form is a simple, nonlinear power function (hereafter called the *NLCW* model):

$$CW = b_1 + b_2 DBH^{b_3} \qquad (1)$$

where crown width (*CW*) is a function of tree diameter at breast height (*DBH*) and species-specific regression coefficients (b_1 to b_3) [note that the linear crown width model is a special case of (1) where $b_3 = 1$]. Capable of expressing different crown size patterns, Equation (1) also has the advantage of being much easier to calculate than other more complicated formulations (e.g., Zavitkovski et al. 1974, Baldwin and Peterson 1997, Dubrasich et al. 1997).

Trees respond noticeably to stand density: open-grown individuals (those living free from competition with other trees) tend to develop more extensive crowns (both radially and longitudinally) than individuals growing in even partially closed canopies. Researchers have long recognized that individual canopy trees rarely occupy the same space simultaneously (see Krajicek and Brinkman 1957), so that as stand density increases, individual trees die or restrict their crown development. Some have attempted to address variable stand density when predicting crown width (e.g., Curtin 1964, Curtis 1970, Rouvinen and Kuuluvainen 1997), but there is no consistent approach to address the effect of close neighbors on crown width. Local stand basal area seems a logical choice to evaluate competitive influences on crown shape because of its accessibility and relevance. Point estimates of basal area generally do as well as more complicated distance-dependent procedures in assessing competition (Avery and Burkhart 1983, Lorimer 1983, Holmes and Reed 1991), and

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thus have been used in numerous ecological studies (e.g., Lorimer 1983, Holmes and Reed 1991, Bragg et al. 1997). Other crown dimensions have shown sensitivity to stand density: Holdaway (1986) used local basal area to adjust crown length for many Lake States species and found considerable responsiveness. A further advantage to this metric is that local basal area is easy to measure in the field, making it preferable to more labor-intensive competition measures.

The objectives of this study are two-fold: (1) to determine if improvements in crown width prediction can be achieved if local basal area is included as a modifier, and if so, (2) to develop a series of predictive crown width equations for a new forest dynamics model (*NORTHWDS*) of the north-central United States.

Methods and Materials

Field Sampling

During the 1997 growing season, 1,613 trees from 24 species were sampled in northern Wisconsin and Michigan (Table 1). Individual trees were selected according to specific criteria. First, only nonforked trees with "regular" crowns were chosen. This differs from other crown width modeling efforts (e.g., Minor 1951, Rouvinen and Kuuluvainen 1997) that sampled every tree in a predetermined area, or those that followed a systematic sampling strategy (e.g., Gill et al. 2000). The use of regular crowns was an attempt to avoid extremely distorted individuals from unduly influencing the results. However, this is not to say that only perfectly circular crowns were chosen. Well-formed yet somewhat elliptical crowns dominated the sample (Figure 1). Eccentricity (e) can be used as a measure of elliptical versus circular shapes:

$$e = \sqrt{1 - \frac{(CW_{min}/2)^2}{(CW_{max}/2)^2}} \qquad (2)$$

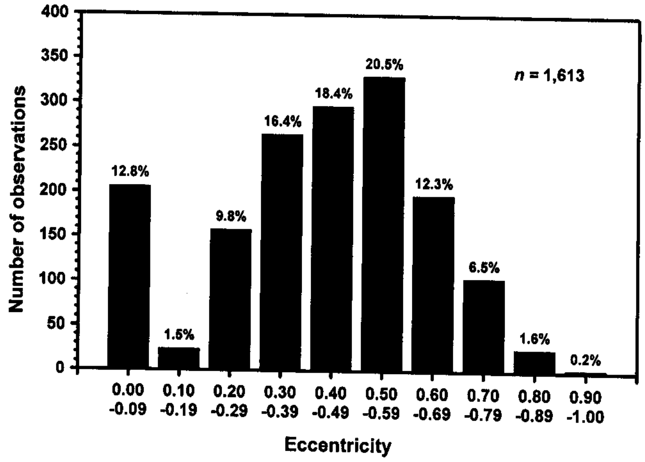

Figure 1. Crown eccentricity patterns of sampled trees (see text for further discussion).

where the minimum and maximum crown widths (CW_{min} and CW_{max}, respectively) determine the degree of difference. A perfect circle, for example, has an $e = 0$, while an increasingly elongated shape has an e that approaches 1. For example, when:

$$CW_{min} = 5.0 \text{ m and } CW_{max} = 5.1 \text{ m}, e = 0.039$$

$$CW_{min} = 5.0 \text{ m and } CW_{max} = 6.0 \text{ m}, e = 0.306$$

$$CW_{min} = 5.0 \text{ m and } CW_{max} = 7.5 \text{ m}, e = 0.556$$

$$CW_{min} = 5.0 \text{ m and } CW_{max} = 10.0 \text{ m}, e = 0.750$$

While no upper eccentricity bound was set, efforts to minimize e in the field were made. Since a primary objective of this project was to predict an "idealized" crown for use in a simulation model, the selection of regular crowns was not anticipated to cause problems.

Table 1. Species, species codes, and initial sample size used to predict crown width.

Common name	Species	Species code	Sample size
Balsam fir	*Abies balsamea* (L.) Mill.	ABIBAL	75
Red maple	*Acer rubrum* L.	ACERUB	81
Sugar maple	*Acer saccharum* Marsh.	ACESAC	150
Yellow birch	*Betula alleghaniensis* Britton	BETALL	92
Paper birch	*Betula papyrifera* Marsh.	BETPAP	64
White ash	*Fraxinus americana* L.	FRAAME	41
Black ash	*Fraxinus nigra* Marsh.	FRANIG	45
Eastern larch	*Larix laricina* (Du Roi) K. Koch	LARLAR	45
Eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch	OSTVIR	46
White spruce	*Picea glauca* (Moench) Voss	PICGLA	69
Black spruce	*Picea mariana* (Mill.) B.S.P.	PICMAR	59
Jack pine	*Pinus banksiana* Lamb.	PINBAN	98
Red pine	*Pinus resinosa* Ait.	PINRES	99
Eastern white pine	*Pinus strobus* L.	PINSTR	116
Balsam poplar	*Populus balsamifera* L.	POPBAL	25
Bigtooth aspen	*Populus grandidentata* Michx.	POPGRA	63
Quaking aspen	*Populus tremuloides* Michx.	POPTRE	77
Pin cherry	*Prunus pensylvanica* L.	PRUPEN	30
Black cherry	*Prunus serotina* Ehrh.	PRUSER	48
Northern red oak	*Quercus rubra* L.	QUERUB	53
Northern white-cedar	*Thuja occidentalis* L.	THUOCC	62
American basswood	*Tilia americana* L.	TILAME	58
Eastern hemlock	*Tsuga canadensis* (L.) Carr.	TSUCAN	111
American elm	*Ulmus americana* L.	ULMAME	6

The second requirement was to sample trees across the range of dbh's and local stand densities encountered (Table 2) in the upper Lake States. Dbh was recorded to the nearest 0.1 cm, crown width was measured to the nearest 0.1 m (as the average of two perpendicular cross-crown distances), and local stand density was estimated with a 2.5 m^2/ha basal area factor prism for each sampled tree at a randomly located point ≤ 1 m from the stem (the sample tree was not counted in the basal area tally). Finally, to be selected, individual trees needed at least a decade since the last severe local canopy disturbance to allow for readjustment to the altered conditions. Crowns typically react quickly to newly formed gaps, with radial expansion and ingrowth filling the vacated space (Erdmann et al. 1975, Runkle 1982, Frelich and Martin 1988), so more than 10 yr was believed to be sufficient response time. Plantations and trees in residential settings were not sampled to avoid genetically altered or pruned individuals that may have atypical crowns.

Data Analysis

All sampled individuals were included for regression analysis under NLCW [Equation (1)] and adjusted for local basal area (hereafter termed $NLCW_{adj}$):

$$CW = b_1 + b_2 DBH^{b_3} + b_4 LBA \qquad (3)$$

where crown width is a function of species-specific coefficients (b_1 to b_4), dbh, and local basal area (LBA). This model assumes that the influence of competition can be treated as additive, thereby allowing variation in crown widths depending on local stand density. Interaction terms between LBA and dbh were also tested, but did not increase predictability for (3) and thus were discarded. Model evaluation involved comparing adjusted R^2 between the approaches: the $NLCW_{adj}$ crown width model would be considered successful if it explained a higher proportion of the variation in the data set after the number of model factors had been taken into consideration.

Results and Discussion

Most species showed strong trends between crown width and the predictors in (1) and (3), as can be seen from the high adjusted R^2 values (typically > 0.70, Table 3). However, given the selection process that favored regularly shaped crowns, it is not surprising that the predictive capacity of (1) and (3) is greater than some previous efforts (e.g., Koop 1989, Canham et al. 1994, Gill et al. 2000). For those individuals within the sampled dbh and density ranges, predicted crown widths are more than zero under most combinations of size, species, and local density. In reality, all trees have a positive crown width (even if they have no dbh or if they are growing under extremely high basal areas), but the nature of fitted regressions of this form [(3)] could result in negative values if the bounds of the sample range are violated.

A considerable majority (21 of 24) responded to increasing basal area with decreased crown width (b_4 coefficient <

Table 2. Summary of field data on species selected for crown width analysis.

Species	Dbh				Local basal area				Crown width				Eccentricity*			
code	Mean	Min.†	Max.	SD	Mean	Min.	Max.	SD	Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
	(cm)				(m^2/ha)				(m)				(unitless)			
ABIBAL	17.7	3.0	40.4	10.2	26.3	0.0	59.7	11.8	3.3	0.6	5.8	1.3	0.32	0.00	0.72	0.252
ACERUB	23.3	2.5	95.0	16.8	29.1	4.6	57.4	10.7	5.5	1.8	15.0	2.6	0.48	0.00	0.88	0.221
ACESAC	31.6	2.0	95.2	21.9	26.8	0.0	50.5	9.4	7.2	1.8	18.8	3.5	0.42	0.00	0.79	0.194
BETALL	33.1	2.5	98.3	23.1	30.4	0.0	55.1	9.9	7.4	1.8	17.1	3.6	0.45	0.00	0.90	0.196
BETPAP	19.7	2.5	53.1	11.3	20.1	0.0	52.8	11.5	4.6	1.8	12.1	2.2	0.47	0.00	0.81	0.199
FRAAME	27.7	3.6	62.0	13.0	29.0	9.2	48.2	8.0	5.8	2.1	12.3	2.4	0.41	0.00	0.81	0.224
FRANIG	19.9	2.3	59.2	13.0	29.6	11.5	48.2	9.2	4.3	1.1	8.5	1.9	0.46	0.00	0.96	0.215
LARLAR	18.7	2.5	49.0	12.3	12.6	0.0	32.1	8.1	3.6	0.9	8.2	2.1	0.34	0.00	0.88	0.262
OSTVIR	12.5	2.8	34.0	7.9	26.7	13.8	41.3	5.9	4.4	2.0	7.6	1.6	0.46	0.00	0.85	0.270
PICGLA	30.7	2.8	62.7	16.3	26.4	0.0	50.5	12.2	4.4	1.4	8.2	1.6	0.39	0.00	0.73	0.192
PICMAR	15.0	3.3	32.5	7.8	17.9	0.0	34.4	7.8	2.6	1.1	7.0	1.2	0.40	0.00	0.87	0.236
PINBAN	20.8	2.8	49.5	9.6	18.1	0.0	45.9	10.3	3.4	1.0	9.3	1.5	0.44	0.00	0.80	0.184
PINRES	29.3	2.5	71.9	18.3	29.9	0.0	66.6	15.8	4.7	1.0	11.7	2.5	0.40	0.00	0.93	0.226
PINSTR	54.3	3.8	113.0	29.0	29.8	0.0	68.9	11.8	7.5	1.4	15.4	3.5	0.45	0.00	0.84	0.205
POPBAL	17.7	2.5	38.4	12.1	15.5	0.0	39.0	10.4	4.2	1.4	10.0	2.2	0.37	0.00	0.76	0.257
POPGRA	29.8	3.0	61.5	14.9	23.8	0.0	52.8	10.1	5.6	1.2	10.7	2.4	0.45	0.00	0.78	0.207
POPTRE	22.8	2.5	67.1	14.8	20.6	0.0	52.8	11.1	4.8	1.2	11.4	2.4	0.47	0.00	0.83	0.190
PRUPEN	7.7	2.8	16.5	3.4	15.3	0.0	48.2	11.9	2.7	1.4	4.6	0.8	0.38	0.00	0.77	0.255
PRUSER	16.3	2.5	43.7	9.0	18.7	0.0	48.2	12.6	4.0	1.6	6.6	1.4	0.44	0.00	0.85	0.240
QUERUB	28.5	2.5	80.0	19.2	23.9	0.0	39.0	9.3	6.6	1.4	14.5	3.6	0.40	0.00	0.80	0.246
THUOCC	30.2	4.3	76.7	14.6	34.3	11.5	64.3	11.6	4.4	1.4	8.6	1.6	0.44	0.00	0.78	0.211
TILAME	31.8	2.8	71.9	14.6	25.2	0.0	41.3	6.9	5.7	2.0	10.9	2.0	0.50	0.00	0.83	0.188
TSUCAN	42.2	2.5	107.7	26.1	34.8	6.9	66.6	10.9	7.1	1.4	13.9	3.0	0.42	0.00	0.87	0.211
ULMAME	13.3	7.1	22.4	5.8	23.7	9.2	36.7	10.6	4.3	3.7	5.4	0.7	0.41	0.00	0.81	0.339

* Eccentricity (e) of a crown =

$$\sqrt{1 - \frac{(CW_{min}/2)^2}{(CW_{max}/2)^2}},$$

where $e = 0$ for a perfect circle, and approaches 1 as $CW_{max} >> CW_{min}$.

† Min. = minimum, Max. = maximum, SD = standard deviation.

Table 3. Regression summary of nonlinear crown width models including a local basal area adjustment (*$NLCW_{adj}$*) and those without (*NLCW*). Shade tolerance (*ST*) scores are adapted from Graham (1954).

Species code	ST	Model*	b_1	b_2	b_3	b_4	Probability $b_4 \neq 0$	Adjusted R^2	MSE†
ABIBAL	9.8	$NLCW_{adj}$	−1.148370	1.484774	0.398922	0.000989	0.8629	0.7926	0.323
		NLCW	−1.142100	1.499522	0.396995			0.7954	0.323
ACERUB	5.9	$NLCW_{adj}$	1.946356	0.277289	0.852833	−0.014818	0.1651	0.8510	0.966
		NLCW	1.644354	0.248532	0.875754			0.8493	0.990
ACESAC	9.7	$NLCW_{adj}$	2.119782	0.346366	0.813395	−0.017616	0.0809	0.8893	1.297
		NLCW	1.703430	0.324161	0.828794			0.8878	1.324
BETALL	6.3	$NLCW_{adj}$	1.297470	0.697196	0.670675	−0.023695	0.0243	0.9268	0.885
		NLCW	0.723785	0.666365	0.677279			0.9233	0.937
BETPAP	1.0	$NLCW_{adj}$	2.223017	0.067197	1.243736	−0.022022	0.0121	0.8681	0.577
		NLCW	1.933184	0.048920	1.325343			0.8567	0.638
FRAAME	5.0	$NLCW_{adj}$	4.067896	0.126510	1.055638	−0.087031	< 0.0001	0.8552	0.749
		NLCW	1.742014	0.098761	1.113605			0.7712	1.216
FRANIG	2.4	$NLCW_{adj}$	1.044675	0.429465	0.719439	−0.009582	0.4772	0.8105	0.615
		NLCW	0.648349	0.470476	0.700000			0.8125	0.623
LARLAR	0.8	$NLCW_{adj}$	1.325384	0.127903	1.064072	−0.055023	< 0.0001	0.9131	0.337
		NLCW	0.763092	0.125368	1.056165			0.8693	0.520
OSTVIR	9.5	$NLCW_{adj}$	−11.033100	10.786200	0.146459	0.005400	0.7541	0.8156	0.421
		NLCW	−10.333500	10.239960	0.152706			0.8195	0.422
PICGLA	6.8	$NLCW_{adj}$	1.653061	0.290016	0.730953	−0.026987	< 0.0001	0.8632	0.312
		NLCW	0.934983	0.303404	0.718580			0.8197	0.418
PICMAR	6.4	$NLCW_{adj}$	1.500497	0.013990	1.662184	−0.017577	0.0796	0.7832	0.302
		NLCW	1.304953	0.008827	1.787981			0.7755	0.319
PINBAN	1.8	$NLCW_{adj}$	1.137072	0.140111	1.008064	−0.037716	< 0.0001	0.8978	0.223
		NLCW	1.030976	0.049391	1.269472			0.8379	0.358
PINRES	2.4	$NLCW_{adj}$	1.454644	0.131228	1.004795	−0.023031	< 0.0001	0.9520	0.290
		NLCW	1.066601	0.088879	1.090938			0.9317	0.417
PINSTR	4.4	$NLCW_{adj}$	1.419708	0.367860	0.762768	−0.048905	< 0.0001	0.8924	1.279
		NLCW	1.180847	0.131145	0.969578			0.8712	1.545
POPBAL	0.7	$NLCW_{adj}$	1.716823	0.282155	0.893641	−0.072609	< 0.0001	0.9066	0.385
		NLCW	2.292949	0.006774	1.855259			0.8230	0.764
POPGRA	0.7	$NLCW_{adj}$	1.899554	0.127094	1.045309	−0.033460	0.0021	0.8841	0.602
		NLCW	1.228857	0.132852	1.024800			0.8642	0.705
POPTRE	0.7	$NLCW_{adj}$	0.917085	0.426571	0.772969	−0.034042	0.0004	0.8966	0.568
		NLCW	0.452656	0.436079	0.750000			0.8784	0.677
PRUPEN	0.7	$NLCW_{adj}$	1.260218	0.130841	1.130661	0.004834	0.5483	0.6128	0.229
		NLCW	1.250506	0.155850	1.077472			0.6221	0.232
PRUSER	2.4	$NLCW_{adj}$	0.396623	1.047267	0.502013	−0.026799	0.0030	0.7279	0.464
		NLCW	0.397577	0.856605	0.526893			0.6760	0.565
QUERUB	5.2	$NLCW_{adj}$	1.796712	0.546874	0.758820	−0.077570	< 0.0001	0.9258	0.913
		NLCW	0.695116	0.376525	0.830740			0.8902	1.380
THUOCC	5.0	$NLCW_{adj}$	1.933244	0.146711	0.898806	−0.018520	0.0105	0.8461	0.349
		NLCW	0.647299	0.283876	0.764190			0.8324	0.387
TILAME	8.2	$NLCW_{adj}$	2.563005	0.069720	1.133592	−0.016178	0.3266	0.8195	0.663
		NLCW	2.186146	0.070577	1.127812			0.8163	0.675
TSUCAN	10.0	$NLCW_{adj}$	1.442937	0.991358	0.540750	−0.040759	< 0.0001	0.8626	1.210
		NLCW	0.264749	0.796417	0.589485			0.8434	1.392
ULMAME	4.0	$NLCW_{adj}$	4.097250	0.025662	1.343831	−0.026273	0.2253	0.4238	0.084
		NLCW	3.143002	0.089564	1.000000			0.3511	0.142

* *$NLCW_{adj}$* = nonlinear crown width adjusted model; *NLCW* = nonlinear crown width model.
† MSE (mean square error) = Σ(Observed crown width − predicted crown width)^2 / number of observations.

0, Table 3). In addition, 15 of the 24 species considered had b_4 coefficients significantly ($P < 0.05$) different from zero (Table 3). Of the remainder, six had b_4 values nonsignificantly less than zero and three had b_4 values greater than zero (but not statistically different from zero). While positive b_4 coefficients seem counter to most assumptions of crown behavior, some trees may respond like this under certain scenarios. A few studies have noted a change in crown architecture for overtopped individuals (Hashimoto 1990, Sakai 1990, O'Connell and Kelty 1994), resulting in progressively wider crowns under higher stand densities. Under these conditions, trees may attempt to optimize their photosynthetic capacity by concentrating their foliage horizontally (rather than vertically) to capture as many sunflecks as possible (Sakai 1990, O'Connell and Kelty 1994).

Plotting species shade tolerance scores [adapted from Graham (1954)] against b_4 coefficients did not produce a statistically significant trend due to the considerable variability in coefficient values (Figure 2). Northern red oak (*Quercus rubra* L.) and white ash (*Fraxinus americana* L.) (mid-tolerant species) and balsam poplar (*Populus balsamifera* L.) (very intolerant) appeared especially sensitive to local basal area while pin cherry (*Prunus pensylvanica* L.) (very intolerant), black ash (*Fraxinus nigra* Marsh.) (intolerant) eastern

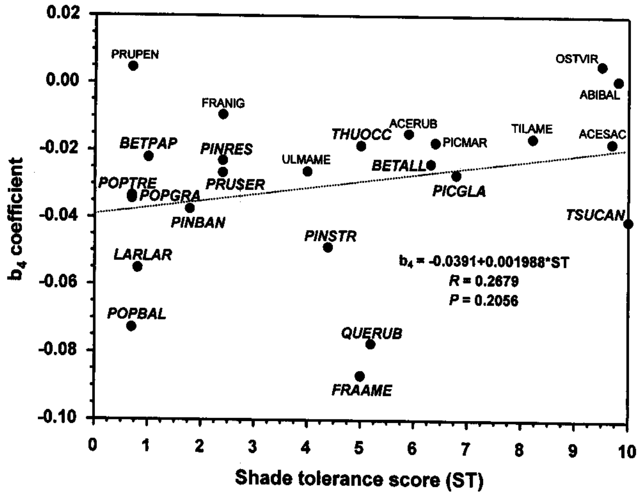

Figure 2. Comparison of local basal area $NLCW_{adj}$ response coefficients (b_4) and shade tolerance scores [adapted from Graham (1954)]. The weak overall trend between shade tolerance and b_4 values is not statistically different from zero ($P = 0.2056$). Individual species with b_4 coefficients significantly different from zero ($P < 0.05$) are in a larger, bold, italicized font.

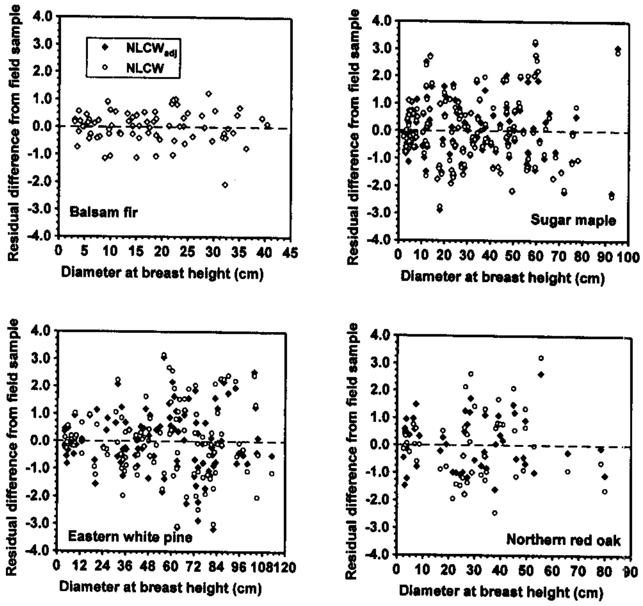

Figure 3. Comparison of residual crown widths of both models for a group of species displaying a range of b_4 values. Balsam fir and sugar maple appear to have relatively similar residual values regardless of model, while eastern white pine and northern red oak show lesser variation for the $NLCW_{adj}$ model when compared to the *NLCW* model.

hophornbeam (*Ostrya virginiana* [Mill.] K. Koch), and balsam fir (*Abies balsamea* [L.] Mill.) (both very shade tolerant) showed very little response to increasing stand density. While Holdaway (1986) found that conifers tended to have larger crown ratios (lengths) than hardwoods, no consistent pattern between broad taxa types appeared in this study (Figure 2). Even though Holdaway (1986) did not compare shade tolerance scores directly to crown length, some open-grown shade intolerant conifers [e.g., jack pine (*Pinus banksiana* Lamb.) or eastern larch (*Larix laricina* [Du Roi] K. Koch)] developed as much crown ratio as shade tolerant species [e.g., balsam fir or eastern hemlock (*Tsuga canadensis* [L.] Carr.)] under similar conditions. Thus, dimensional crown response to local basal area appears to be more of a function of species autecology rather than a trend consistent across a trait like shade tolerance.

Many of the species in this study that showed increases in adjusted R^2 did not exhibit dramatic improvements in model fit. On average, adjusted R^2 values increased only about 2.5% for the $NLCW_{adj}$ design (Table 3), although some species fared better (over 8% improvement). While the pattern in adjusted R^2 suggests a noticeable trend, the issue of biological significance may be raised. Indeed, the comparison of the species included in Figures 3 and 4 provides mixed results. Northern red oak and eastern white pine (*Pinus strobus* L.), with their relatively high b_4 coefficients, showed residual crown width reductions from 1 to 2 m on some individuals with 10 to 15 m wide crowns, an improvement of about 10%. Most individual northern red oaks and eastern white pines experienced some benefit from the inclusion of local basal area, though not of the same magnitude. Balsam fir and sugar maple (*Acer saccharum* Marsh.), conversely, barely recorded any positive changes. The gain of a few percentage points in crown width prediction accuracy may seem minor, but it can still have a significant impact on the performance of simulation models dependent on this or related parameters. This is especially true when projecting large areas for which errors in crown size estimates are additive. As an example, consider the effect when predicting the volume of a simple cone-shaped crown. If a 5% difference in crown diameter is assumed (9.5 m versus 10 m) on an individual with a 10 m long crown, then the predicted crown volume difference is approximately 10% (236 m^3 versus 262 m^3). An improvement of this magnitude would appear to be worth the effort to calculate, especially if considered over large spatiotemporal scales. It is possible that the sensitivity of

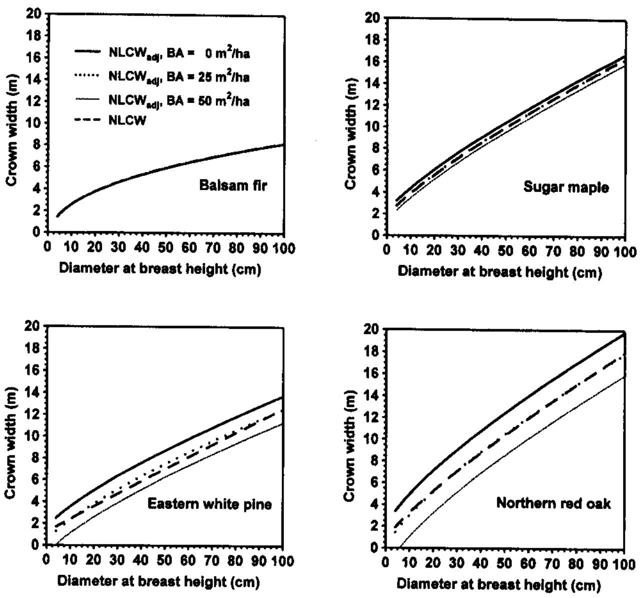

Figure 4. Translating the $NLCW_{adj}$ and *NLCW* models into generalized patterns showing the differences in predicted performance. For those species (e.g., balsam fir) insensitive to local basal area, predictions for both model types under all density conditions vary little. As sensitivity progressively increases, the disparity between the models becomes more apparent. $NLCW_{adj}$ and *NLCW* models differ very little when local basal area ≈25 m^2/ha.

the $NLCW_{adj}$ will increase substantially if more open-grown (or low stand density) sites are collected and included in the analysis. The heavily forested study region made it very difficult to collect more than a handful of individuals growing in low density conditions, limiting their impact on the regression results.

Interestingly, local stand density was not influential enough to be included in the final crown models from a recent study of conifers in California (Gill et al. 2000). They found dbh alone was sufficient to predict crown radius and that adding a basal area parameter yielded little to no improvement. The apparent discrepancy between Gill et al. (2000) and this study's results may have several possible explanations. First, Gill et al. (2000) applied a substantially different crown measurement design, which may not prove sensitive to local density. They used perpendicular crown radii measures and truncated crown radius at the intersection of neighboring trees (rather than the full overlap), both of which could mask local basal area effects. Second, Gill et al. (2000) may not have sufficiently covered the extremes of the stand density spectrum when applying basal area if they used average stand densities rather than localized point estimates (their exact methodology is not clear). Finally, it is possible that interspecific differences between western conifers and midwestern species are sufficient to influence the results. Perhaps even the greater vertical stratification of western coastal forests could interact with crown response patterns to yield no significant results. Any model lacking the ability to control for changes in stand density would predict the same crown width for a tree growing in open-grown conditions as one found in a dense stand. This is contrary to expectations, which would not hold open-grown individuals to be as constrained as in closed canopies where lateral light interference and crown collision damage occurs.

Conclusions

Reliable estimation of the physical dimensions of trees is a critical component in silvicultural and ecological research. This is especially true when simulation models are used to project extensive areas over long time periods, as these models depend on individual dynamics to shape predicted meta-behavior. Determining how parameters like crown width respond to local environmental conditions (e.g., stand density) should improve our understanding of the biological principles underlying these dynamics, and, hopefully, minimize the propagation of errors over space and time. A crown width model sensitive to local stand density represents a first step in addressing this.

In this study, most species showed improvements in adjusted R^2 when using the $NLCW_{adj}$ model. However, a considerable majority of the species sampled had local basal area coefficients (b_4) significantly less than zero, indicating some crown width response to stand density. Only the four species with the lowest b_4 coefficients (balsam fir, black ash, eastern hophornbeam, and pin cherry) did not produce greater explained variation with the $NLCW_{adj}$ than the $NLCW$ model. Sensitivity to local basal area may be increased if better representation of very low stand densities was possible. No significant relation between crown width and shade tolerance was detected: shade intolerant species appeared as sensitive (or insensitive) as shade tolerant species to changes in local stand basal area. It appears that adjusting crown width prediction with local basal area estimates can improve the accuracy of their fit, thereby reducing modeling errors. Obviously, not every species is as sensitive as northern red oak, but even relatively small improvements may prove substantial.

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